

# **Green Chemistry and Biomimicry:**

## The next generation of opportunity

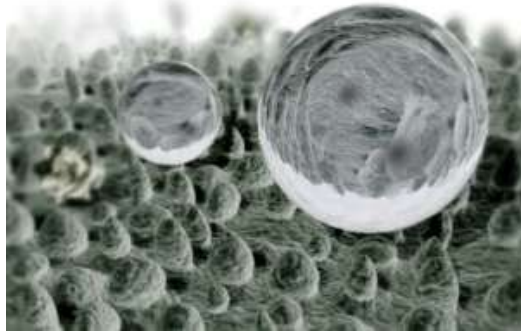
Amy S. Cannon, Ph.D.

Executive Director



# Biomimicry

Biomimicry is the science and art of emulating Nature's best biological ideas to solve human problems.

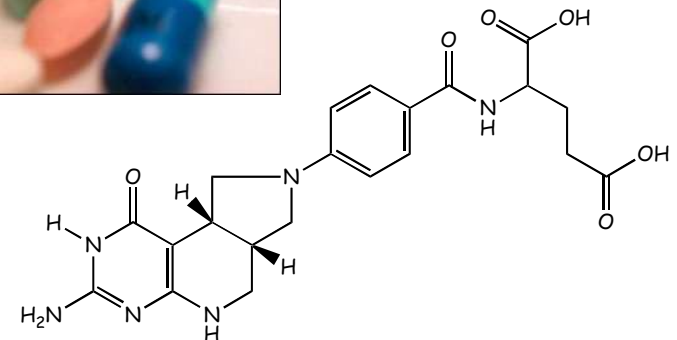


In biomimicry, we look at nature as model, measure, and mentor.

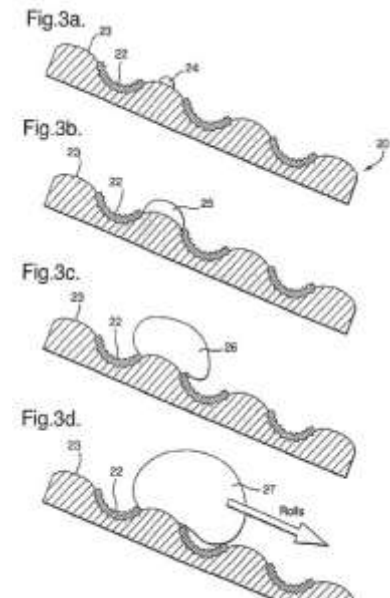
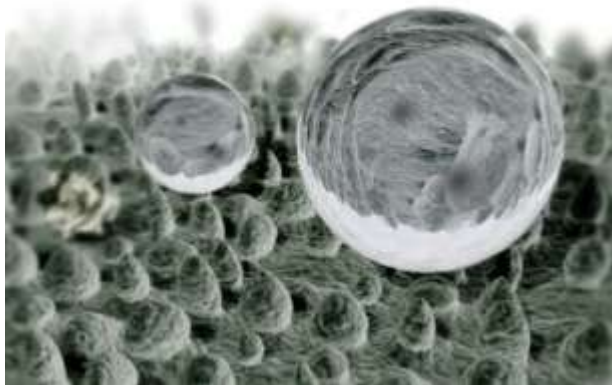
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Teijin Fibers Limited (Japan) – Morphotex®



Humans may have a long way to go towards living sustainably on this planet, but 10-30 million species with time-tested genius have figured it out and maybe we can learn a few things from them?





Biomimicry introduces an era based not on what we can extract from organisms and their ecosystems, but on what we can learn from them.



Japanese Bullet Trains



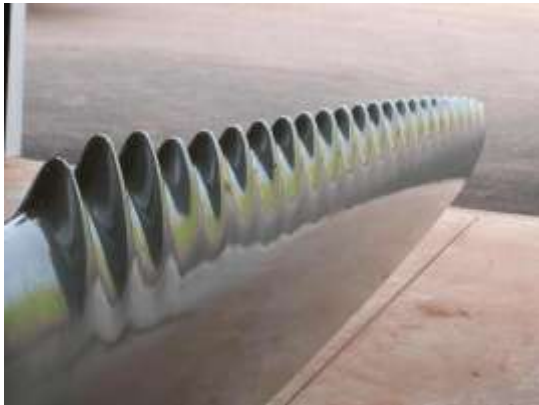
Pax Fans by  
Pax Scientific, Inc.



“Life in the sea must deal with the momentum of tides, currents, waves, and storms. Streamlined shapes, flexible appendages, and low-friction surfaces help minimize the impact of these flows”



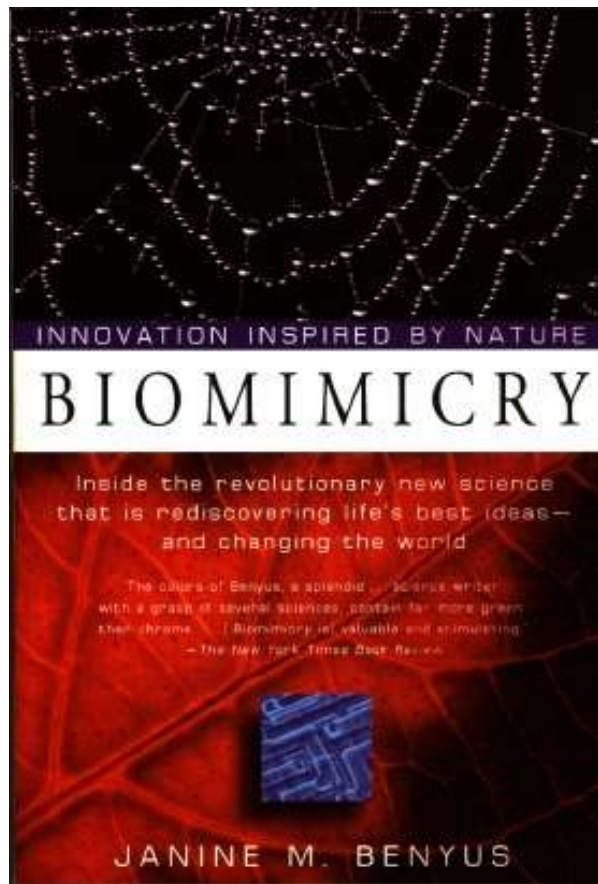
Instead of harvesting or domesticating, biomimics consult organisms; they are inspired by an idea, be it a physical blueprint, a process step in a chemical reaction, or an ecosystem principle. Borrowing an idea is like copying a picture-the original image can remain to inspire others.



[www.worldwildlife.org](http://www.worldwildlife.org)



[biomimicry.net](http://biomimicry.net)



Janine Benyus

How does Biomimicry relate to  
Green Chemistry?



# Sustainability

Economics Agriculture Education Business Chemistry Engineering Others

## Sustainable Chemistry

Chemicals Policy Remediation Technologies Exposure Controls Green Chemistry Water Purification Alternative Energy Others

## Green Chemistry

Solvents Catalysts Renewable Feedstocks Reduced Toxicity Non Persistent Reduced Energy Others

# Sustainability

Economics Agriculture Education Business Chemistry Engineering Others

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## Green Chemistry

1 2 3 4 5 6 7 8 9 10 11 12

## **One can do Biomimicry without Green Chemistry**

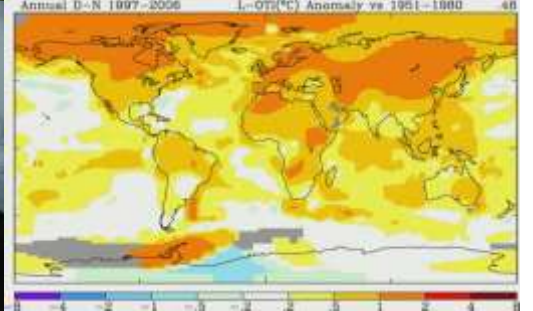
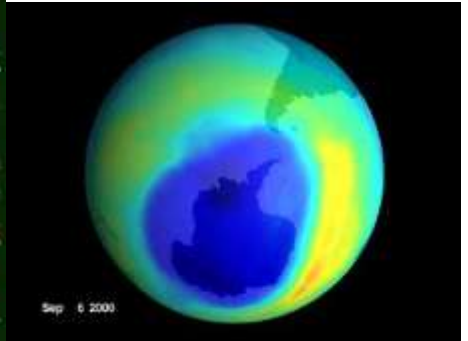
You can make “gecko-like” adhesive from toxic materials

## **One can do Green Chemistry without Biomimicry**

Processes are inherently sustainable in nature.

# **Why do we have pollution and environmental hazards?**

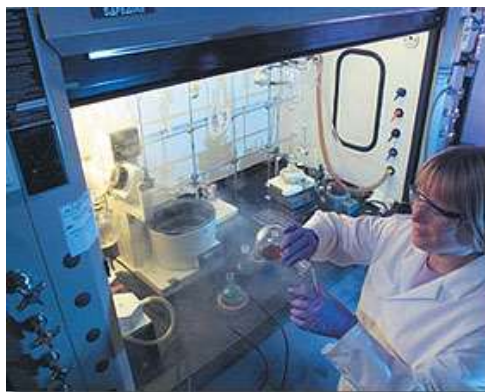




# Chemists' Roles in Environmental Problems

Historically, synthetic chemists have not played a major role in the environmental movement.

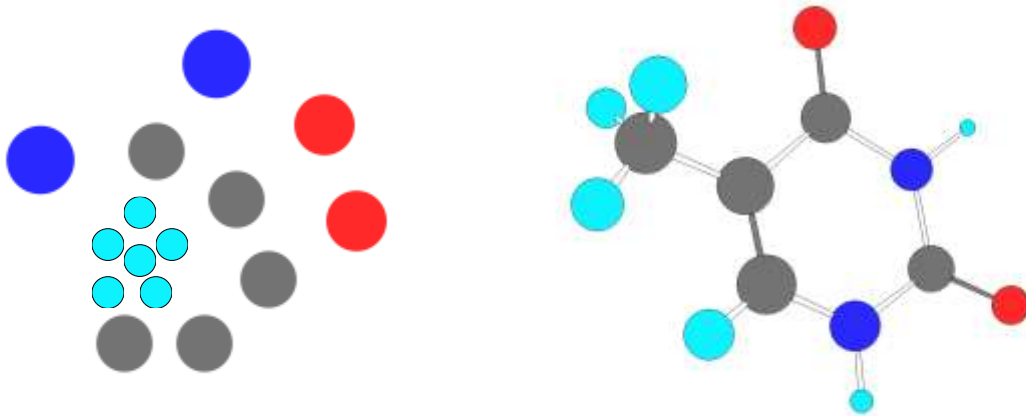
Green Chemistry identifies synthetic chemists as the key practitioners in identifying, developing, and implementing pollution prevention technologies.



The moment a chemist puts pencil to paper, he/she is making determinations about the human health and environmental impacts associated with the chemicals used in or generated from the manufacture, processing, use, and disposal of chemical products.



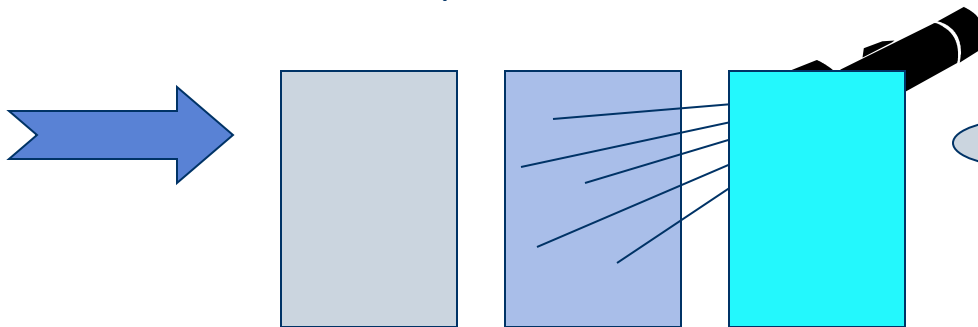
# Where do products come from?



## Materials:

- Polymers
- Micelles
- Semiconductors
- Conductors
- Etc.

## Components and Devices:



## Products:





# Design Criteria

- Solubility
- Melting Point
- Glass transition temperature
- Mechanical Properties (Tensile Strength, Modulus, Elongation)
- Refractive Index
- Surface Tension

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- Solubility
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- **Toxicity**
- **Environmental Impact**

# **Why do we have pollution and environmental hazards?**

*It is not in our language.* It has always been someone else's job.

To get a degree in Chemistry...

**No universities require any demonstration  
of knowledge regarding  
toxicity or environmental impact!**



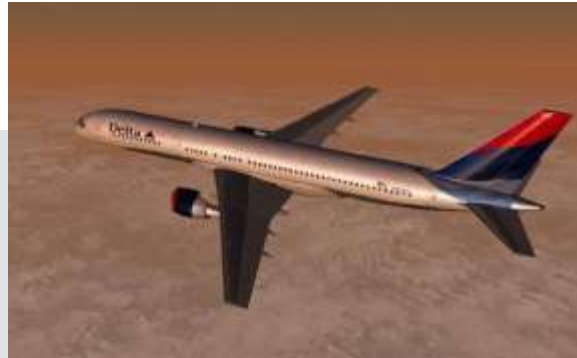
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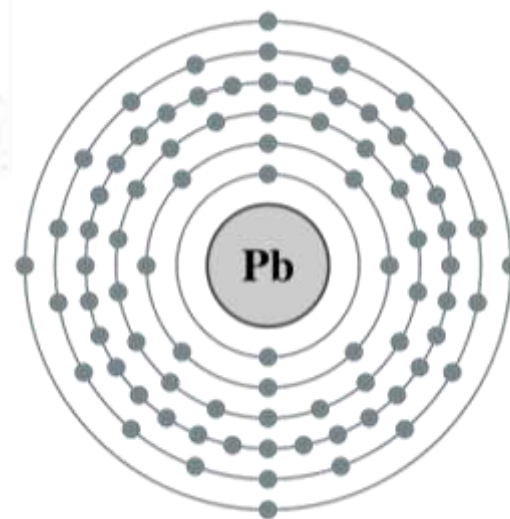
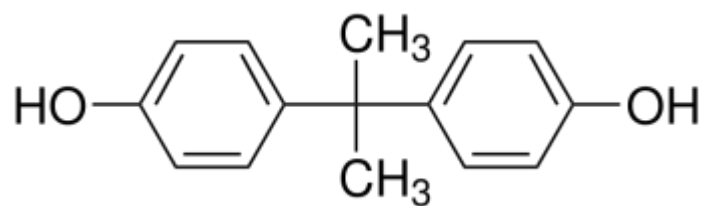
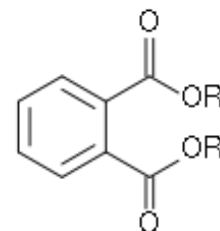
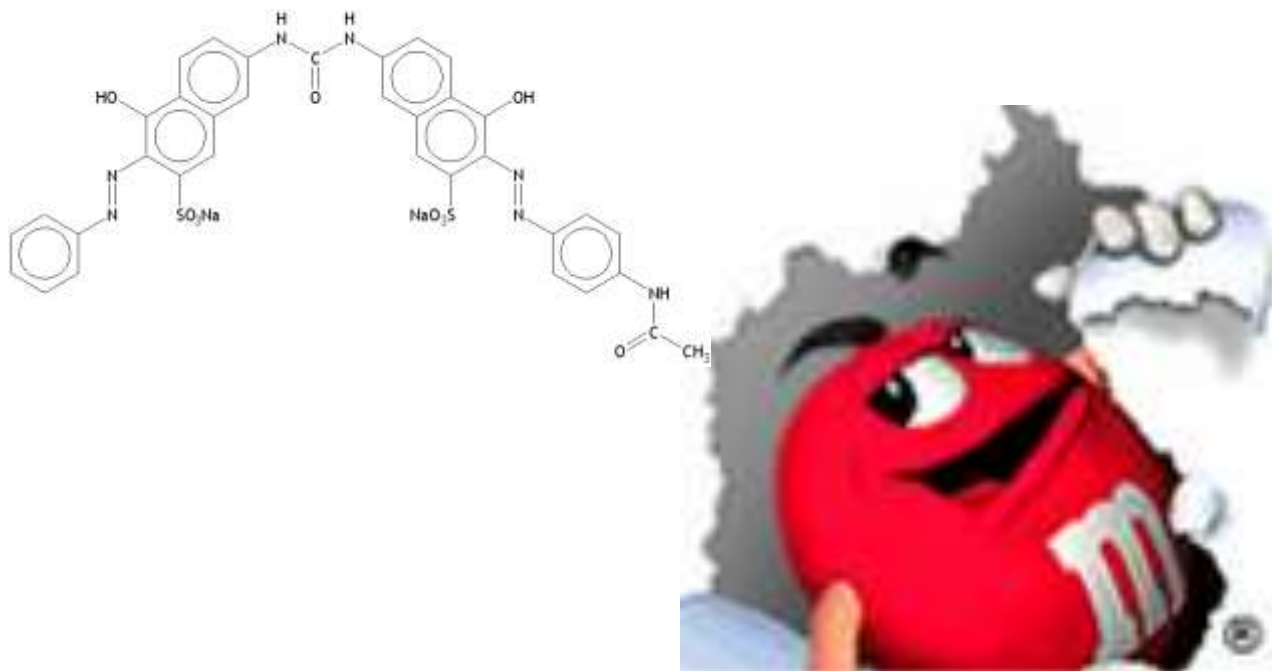
We are simply not taught how to create safe materials.

Chemistry is strange.

# Everyday Hazards



# Unrelated Hazards







$$\text{Risk} = \text{Exposure} \times \text{Hazard}$$

Green Chemistry is the only science where the focus is reducing and/or eliminating the intrinsic hazards.

Chemists and materials scientists have the greatest potential to impact pollution prevention.

# Green Chemistry is about...

- Shifting roles
- Changing education of chemists
- Understanding Intrinsic Hazard
- Design
- Reducing Costs
- Enhancing Performance
- Innovation

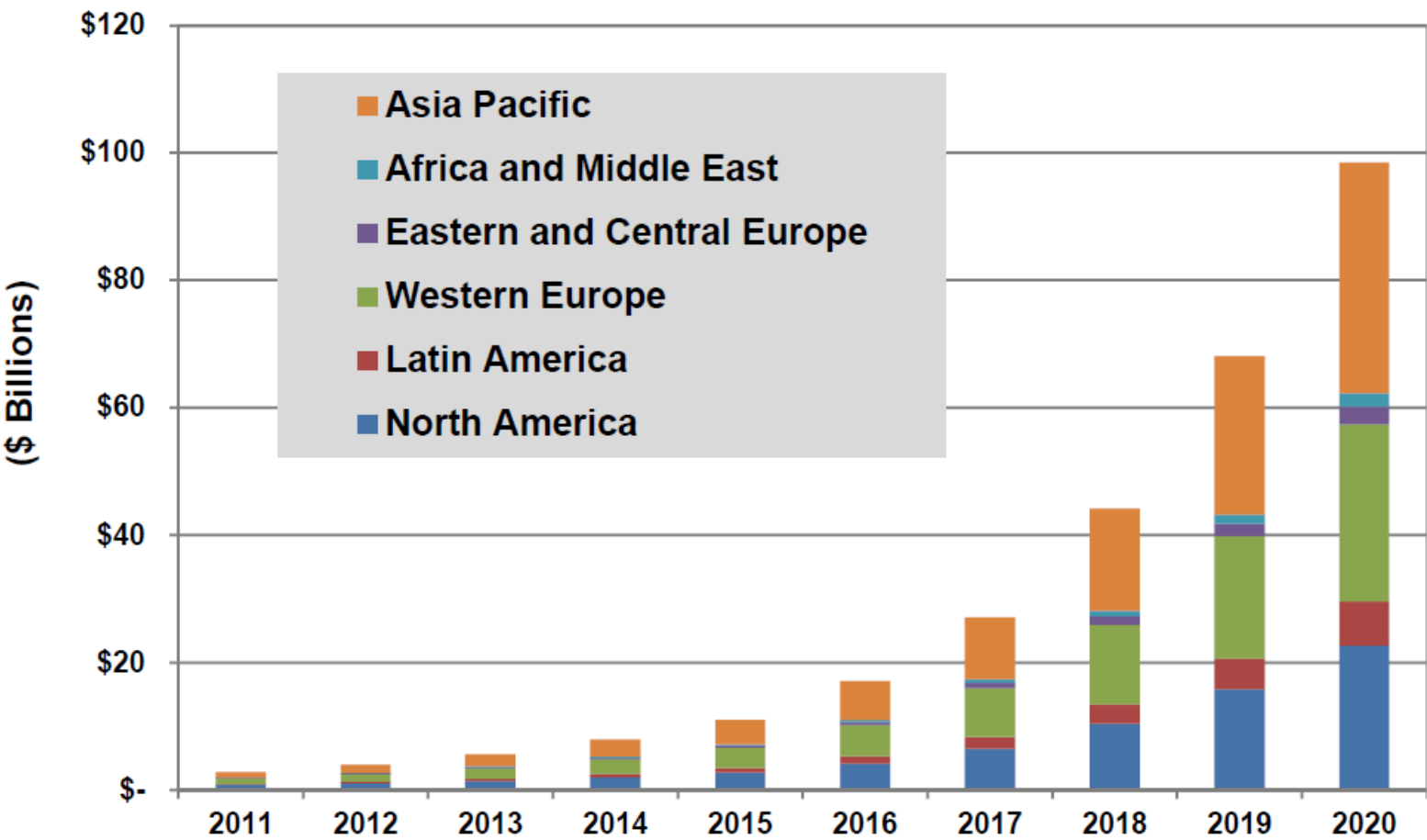
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- ✓ Understanding Intrinsic Hazard
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  - Enhancing Performance
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# Reducing Costs



**Chart 1.1      Green Chemical Market by Region, World Markets: 2011-2020**



*(Source: Pike Research)*

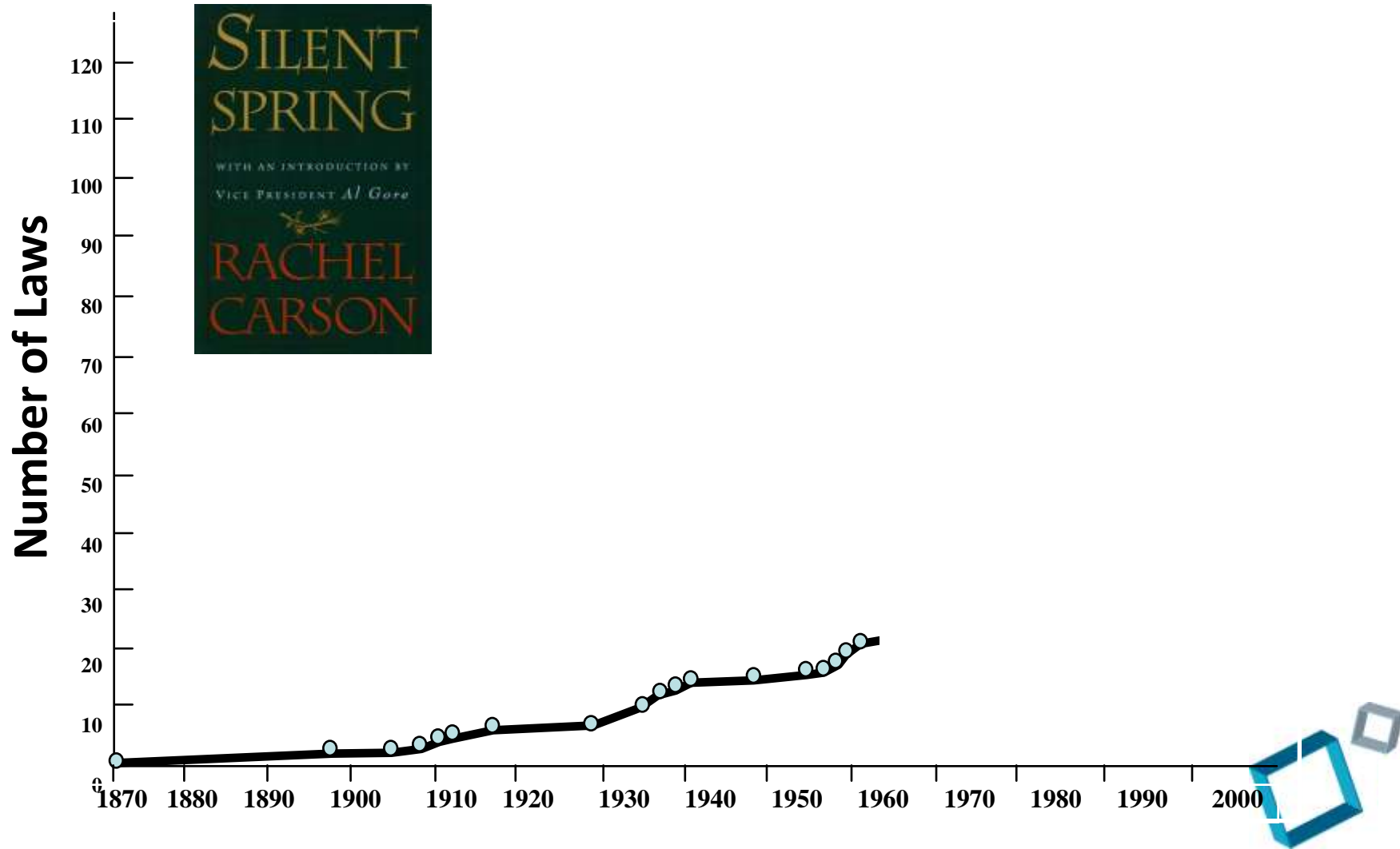
# The cost of using hazardous materials:

- Storage
- Transportation
- Treatment
- Disposal
- Regulatory Costs
- Liability
- Worker Health and Safety
- Corporate Reputation
- Community Relations
- New Employee Recruitment

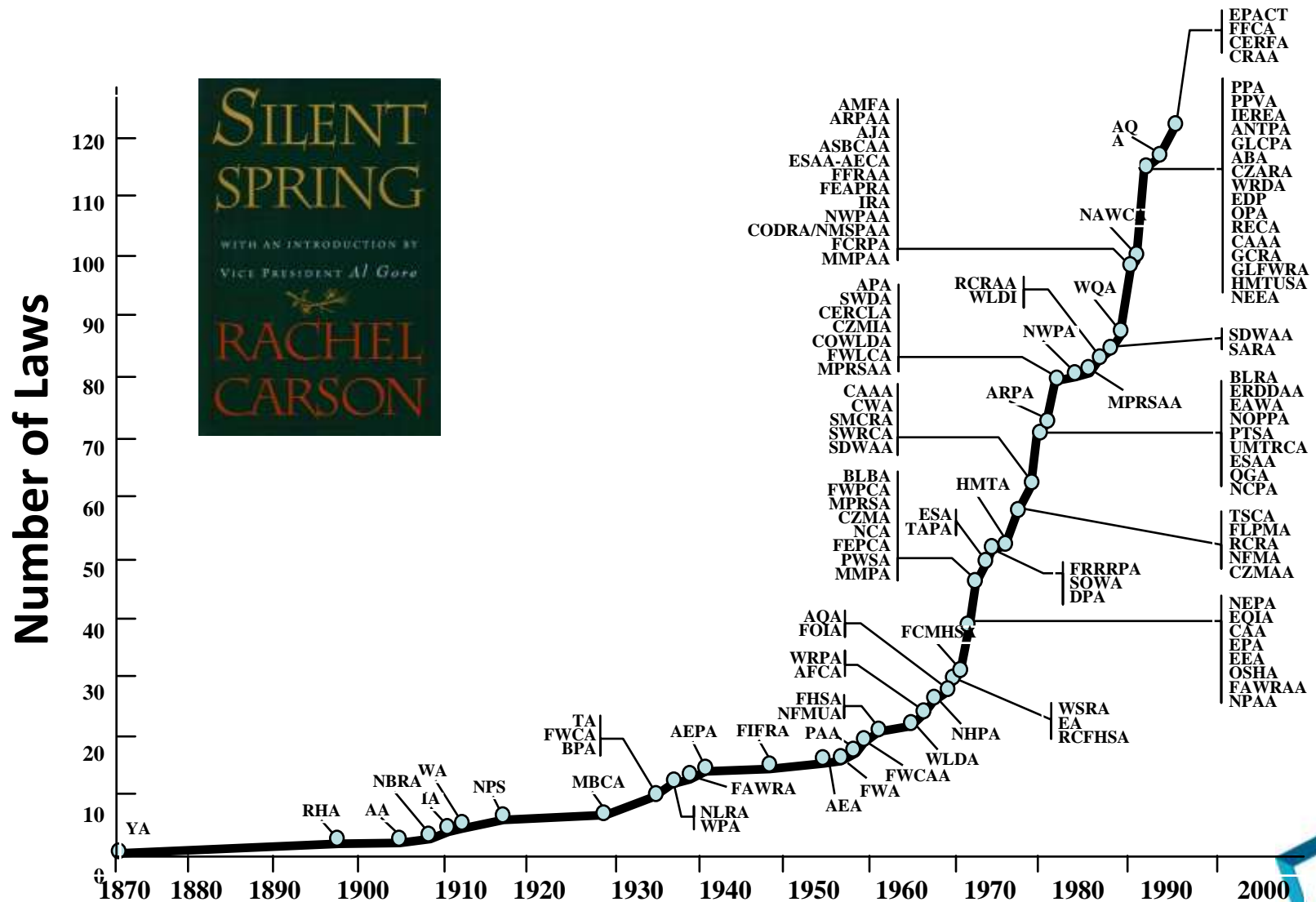




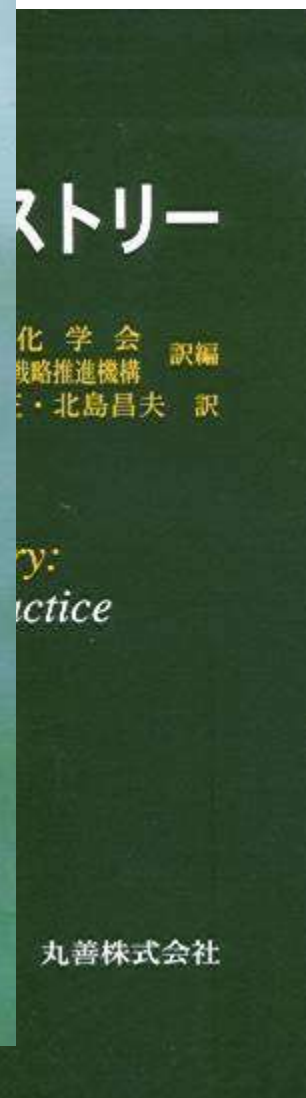
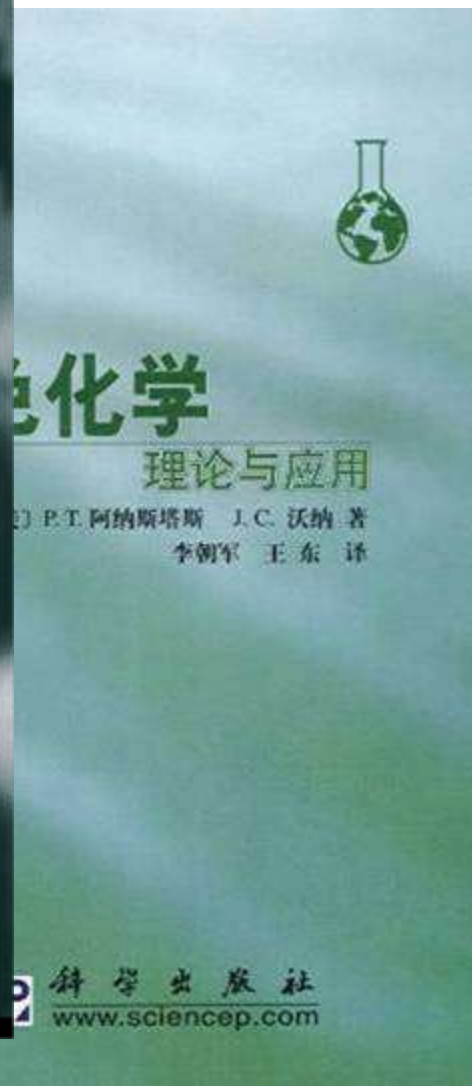
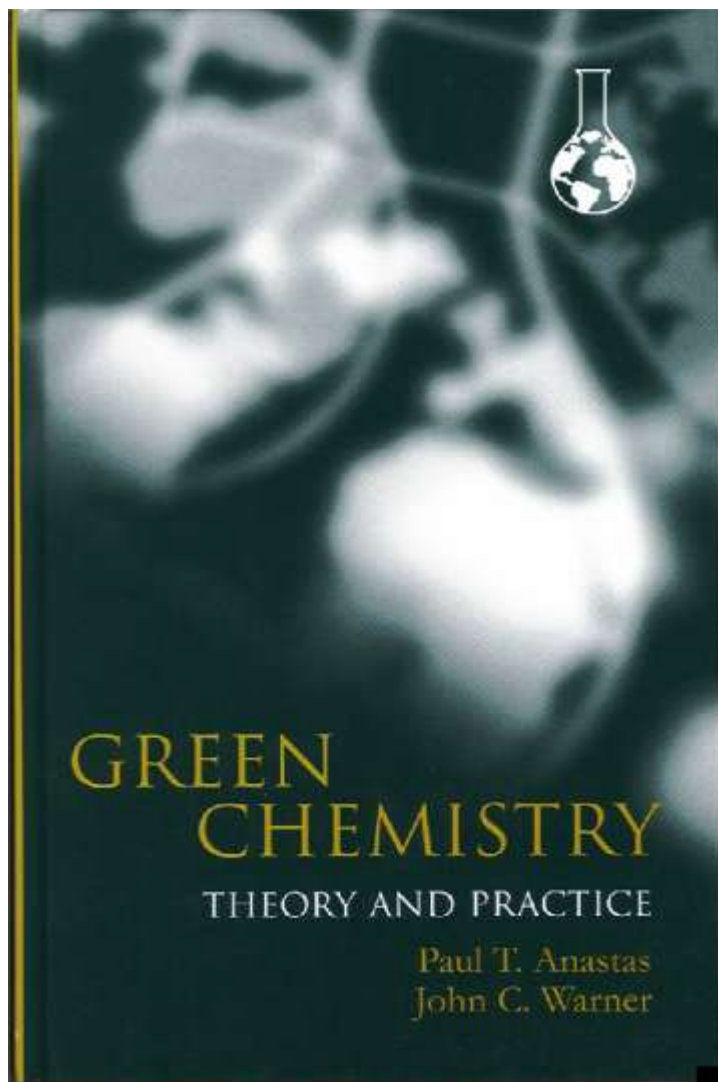
# Environmental Regulations



# Environmental Regulations



Green Chemistry is the *design* of chemical products and processes that reduce or eliminate the *use and/or generation* of hazardous substances.



# The Twelve Principles of Green Chemistry

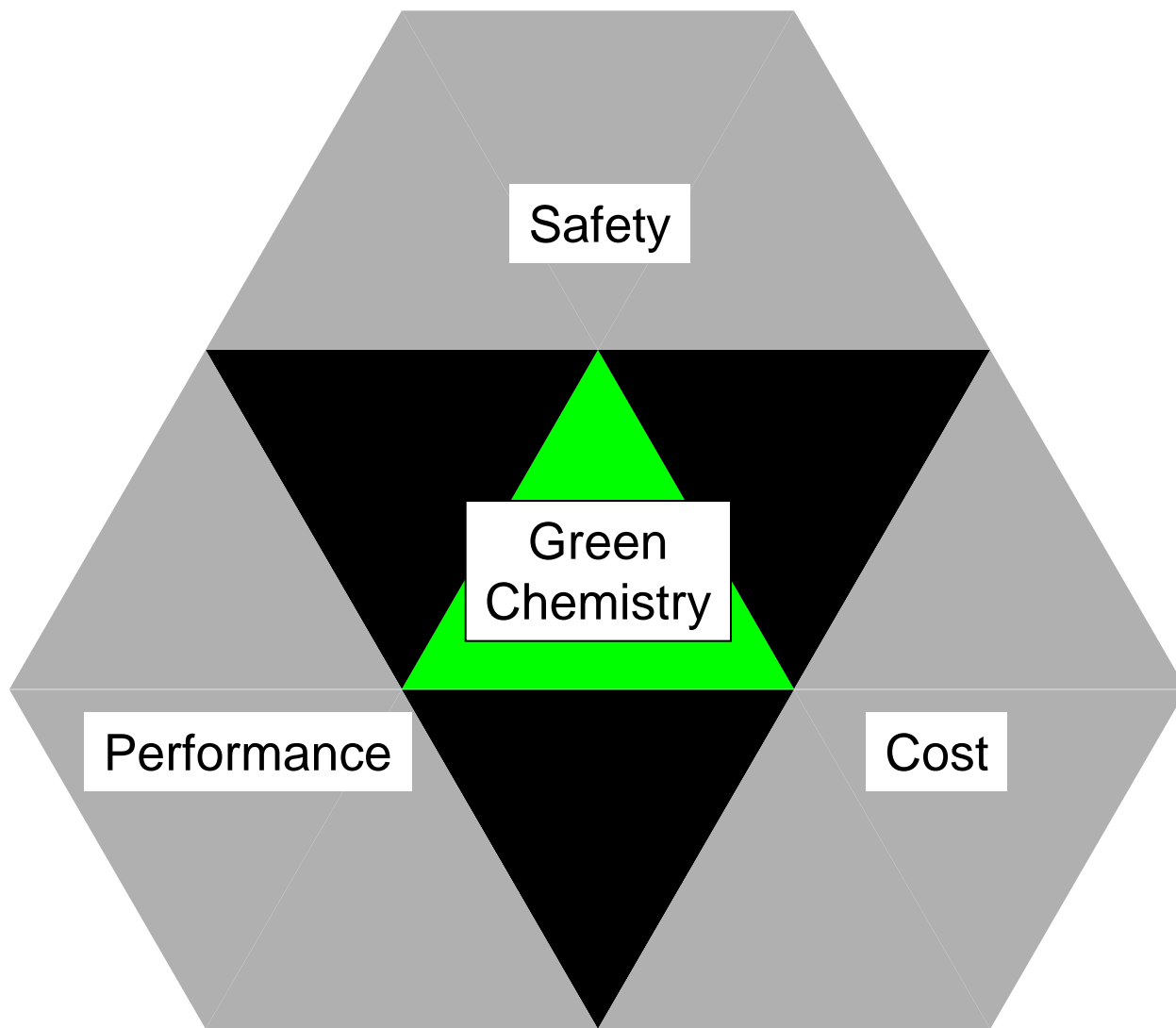
- 1. Prevention.** It is better to prevent waste than to treat or clean up waste after it is formed.
- 2. Atom Economy.** Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product.
- 3. Less Hazardous Chemical Synthesis.** Whenever practicable, synthetic methodologies should be designed to use and generate substances that possess little or no toxicity to human health and the environment.
- 4. Designing Safer Chemicals.** Chemical products should be designed to preserve efficacy of the function while reducing toxicity.
- 5. Safer Solvents and Auxiliaries.** The use of auxiliary substances (solvents, separation agents, etc.) should be made unnecessary whenever possible and, when used, innocuous.
- 6. Design for Energy Efficiency.** Energy requirements should be recognized for their environmental and economic impacts and should be minimized. Synthetic methods should be conducted at ambient temperature and pressure.
- 7. Use of Renewable Feedstocks.** A raw material or feedstock should be renewable rather than depleting whenever technically and economically practical.
- 8. Reduce Derivatives.** Unnecessary derivatization (blocking group, protection/deprotection, temporary modification of physical/chemical processes) should be avoided whenever possible .
- 9. Catalysis.** Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.
- 10. Design for Degradation.** Chemical products should be designed so that at the end of their function they do not persist in the environment and instead break down into innocuous degradation products.
- 11. Real-time Analysis for Pollution Prevention.** Analytical methodologies need to be further developed to allow for real-time in-process monitoring and control prior to the formation of hazardous substances.
- 12. Inherently Safer Chemistry for Accident Prevention.** Substance and the form of a substance used in a chemical process should be chosen so as to minimize the potential for chemical accidents, including releases, explosions, and fires.



More environmentally  
benign than alternatives

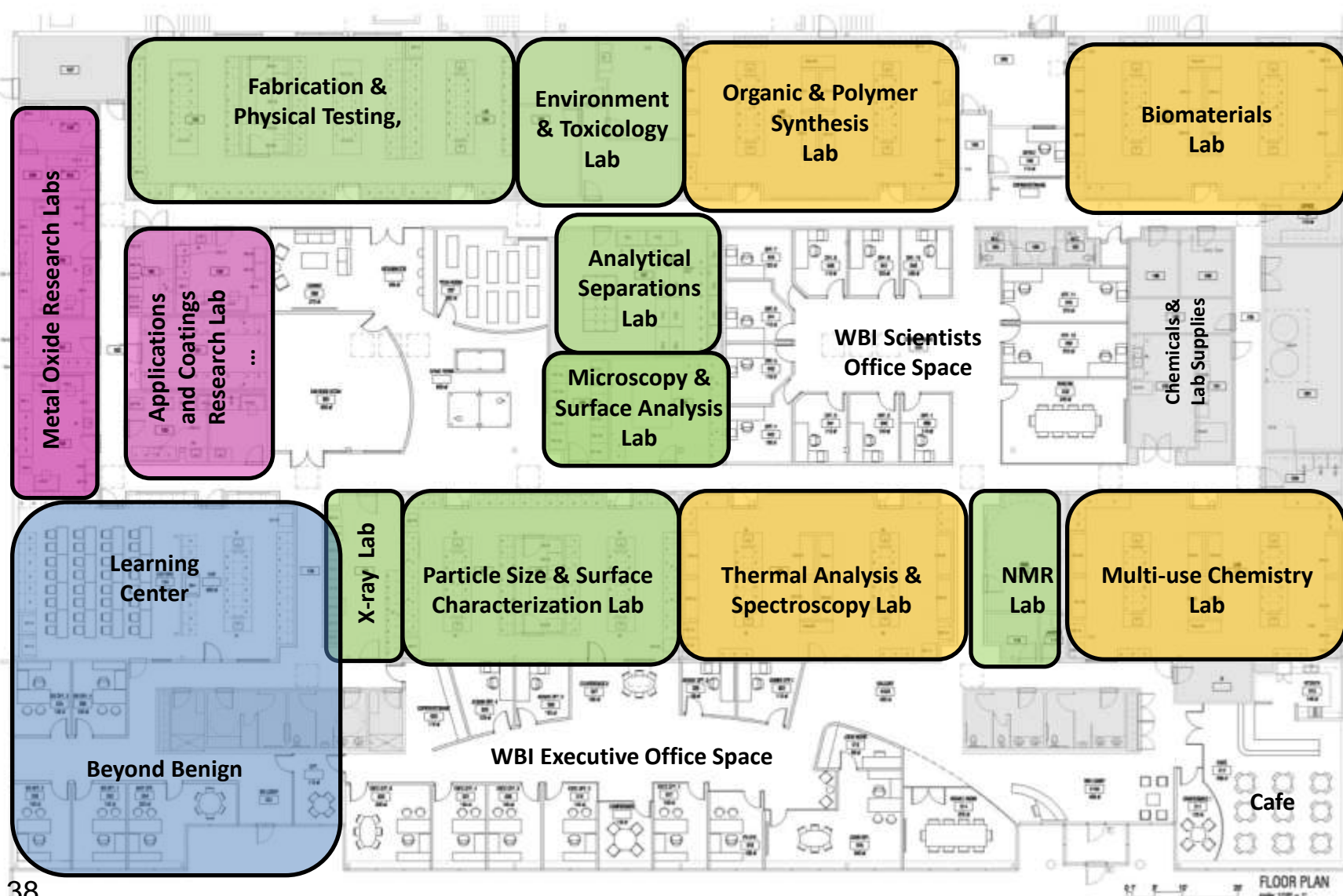
Perform better  
than alternatives

More economical  
than alternatives





# Biomimicry and Green Chemistry: *In practice*



# Ultra Low Cost Non-Toxic Solar



Paul Hawken



Janine Benyus



John Warner

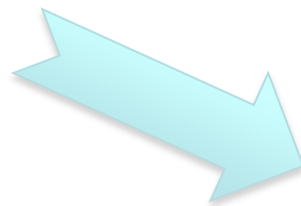




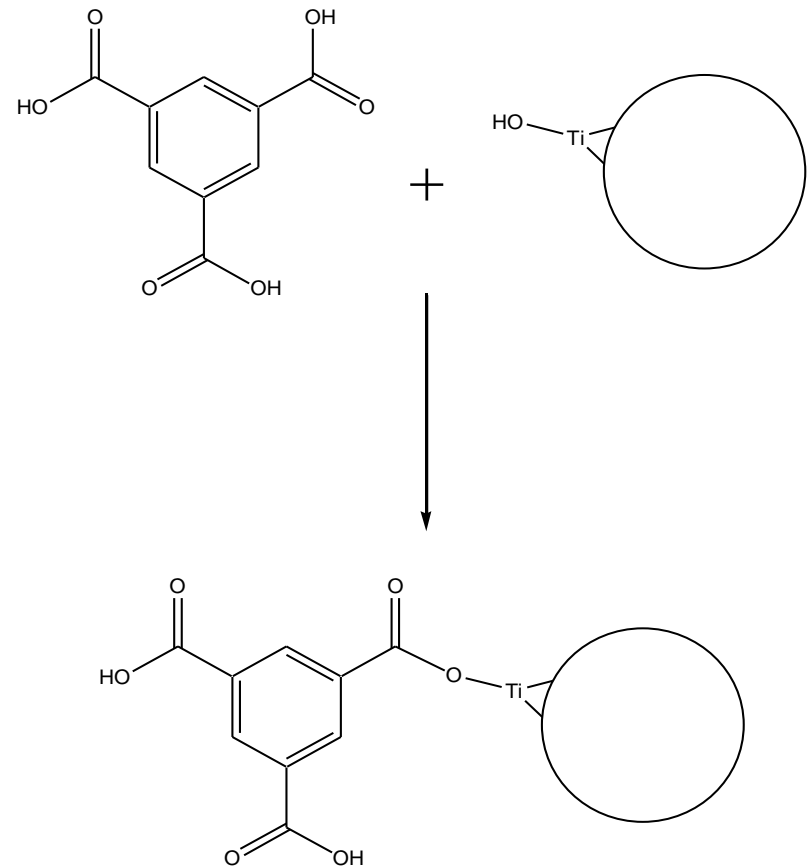
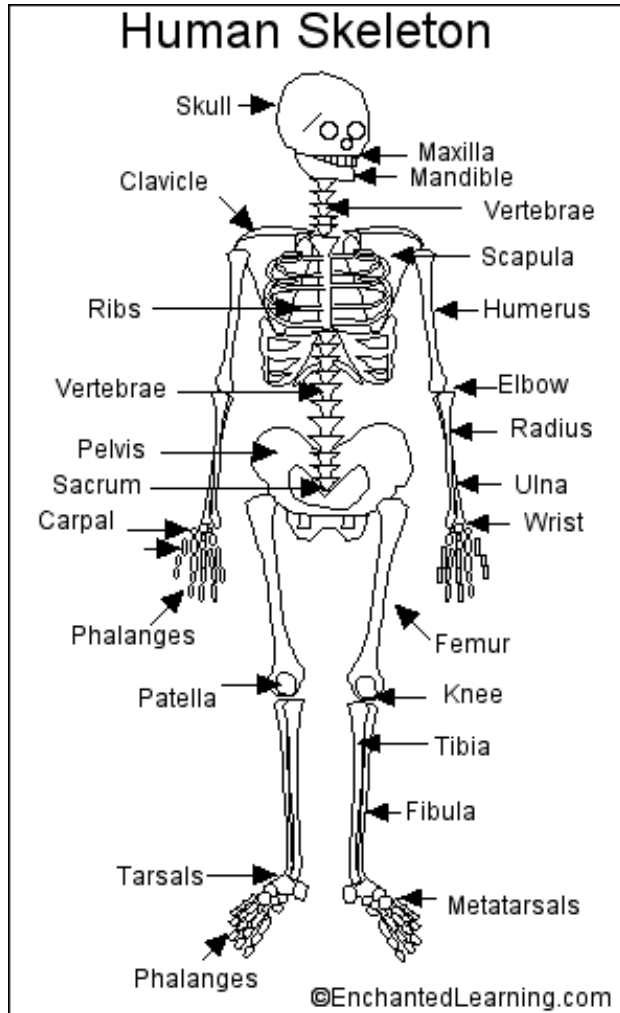
- Expensive
- Toxic Materials
- Energy Intensive
- Long energy buy-back time



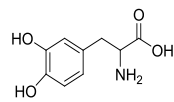
- Low Cost
- Non-toxic Materials
- Low Energy
- Short energy buy-back time



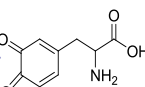
# Bioinspiration



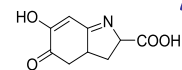
# Nontoxic, Environmentally Benign Hair Coloring



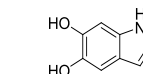
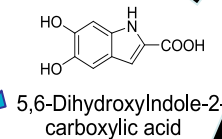
Tyrosinase



DOPAQuinone



L-DOPACHrome



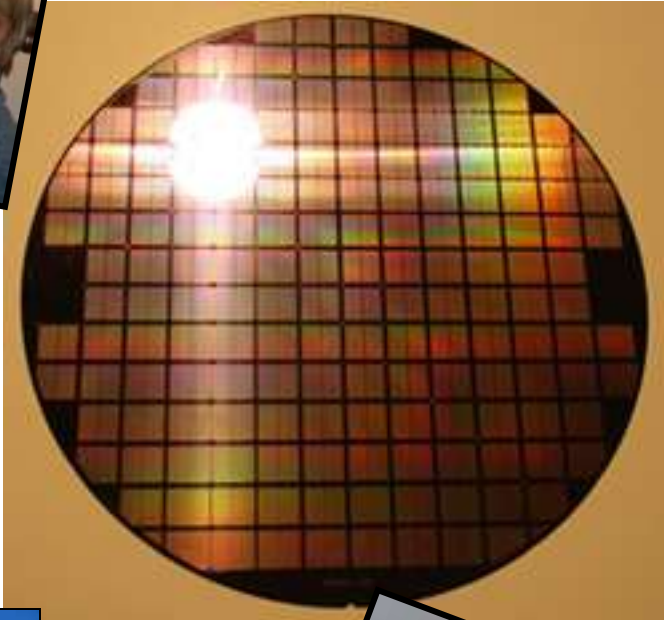
5,6-DihydroxyIndole

Eumelanin:  
Source of Blond to  
Black Pigments

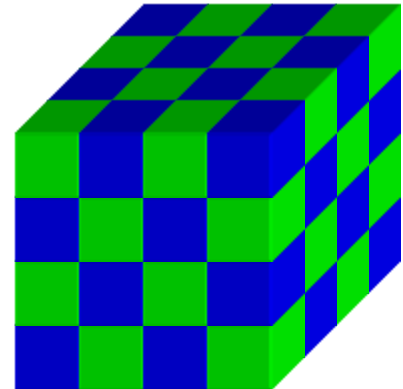




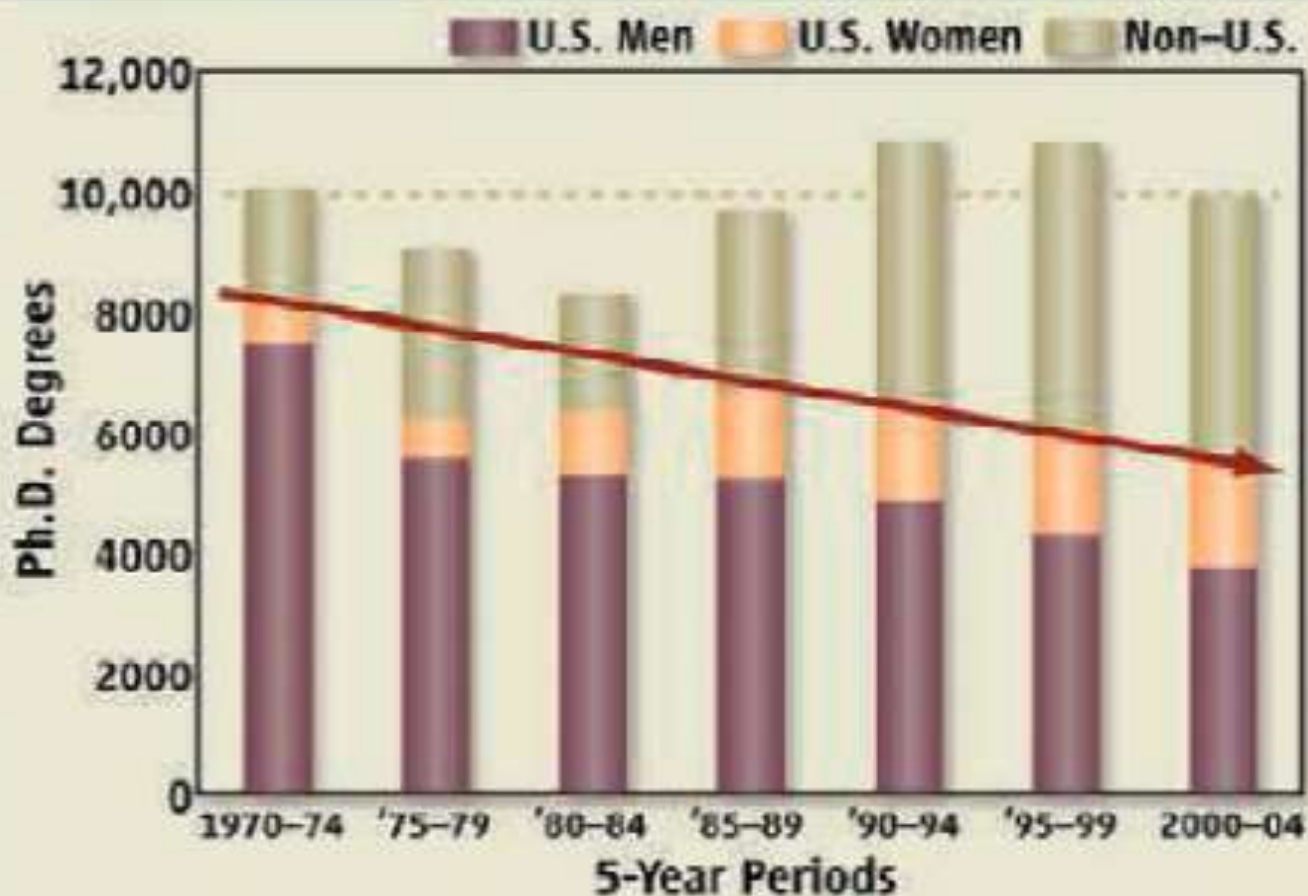
# Water Based Non Toxic Photoresist Cleaning Solutions



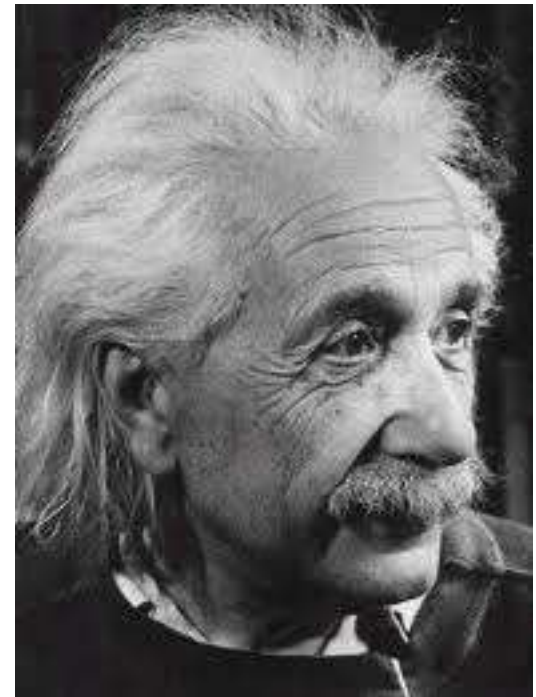
# Increased Bioavailability for a Parkinson's Disease Drug



## Declining Chemistry Ph.D.s at U.S. Universities



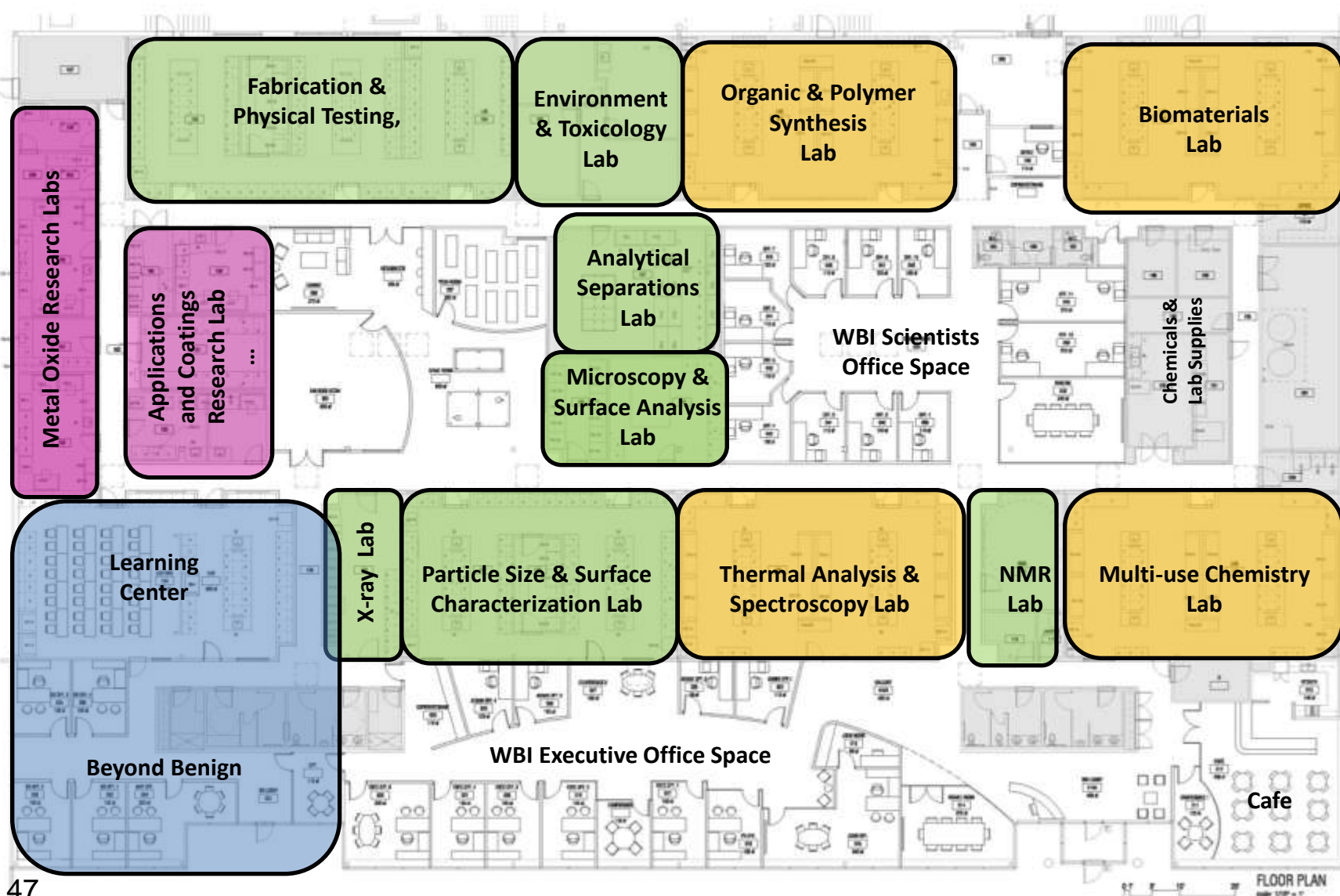
Problems cannot be solved at  
the same level of awareness  
that created them.



Albert Einstein







## MISSION AND VISION

**Beyond Benign is dedicated to providing future and current scientists, educators and citizens with the tools to teach and learn about green chemistry in order to create a sustainable future.**

**Beyond Benign's vision is to revolutionize the way chemistry is taught to better prepare students to engage with their world while connecting chemistry, human health and the environment.**





## K-12

- Curriculum Development and Teacher Training
  - Green Chemistry
  - Green Math & Engineering
  - Biotechnology
- On-line Courses
- Professional Development Workshops
- K-12 and Community Outreach
- College Student Fellows program

## College/University

- The Green Chemistry Commitment
- Curriculum Development and Training
  - Technical Training
  - Green Chemistry training for workers
- Green Chemistry tools



**beyondbenign**  
green chemistry education

[www.beyondbenign.org](http://www.beyondbenign.org)

## K-12

- Curriculum Development and Teacher Training
- **Free!** Open Access Curriculum:
  - Green Chemistry
  - Green Math & Engineering
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  - Green Chemistry tools
- College Student Fellows program
- The Green Chemistry Commitment:  
Transforming chemistry education

# Thank you!

Amy\_Cannon@beyondbenign.org

[www.beyondbenign.org](http://www.beyondbenign.org)

john.warner@warnerbabcock.com

[www.warnerbabcock.com](http://www.warnerbabcock.com)



# More Information: Biomimicry

[www.biomimicryguild.com](http://www.biomimicryguild.com)

[www.biomimicryinstitute.org](http://www.biomimicryinstitute.org)



[www.asknature.org](http://www.asknature.org)

# More Information: Green Chemistry

[www.warnerbabcock.com](http://www.warnerbabcock.com)

[www.beyondbenign.org](http://www.beyondbenign.org)



Green Chemistry Challenge Awards: <http://www.epa.gov/gcc/>